Light Neutralino in the MSSM

a playground for dark matter, flavor physics and collider experiments

Toshihiko Ota

Based on

Lorenzo Calibbi, TO, and Yasutaka Takanishi

JHEP **1107** (2011) 013

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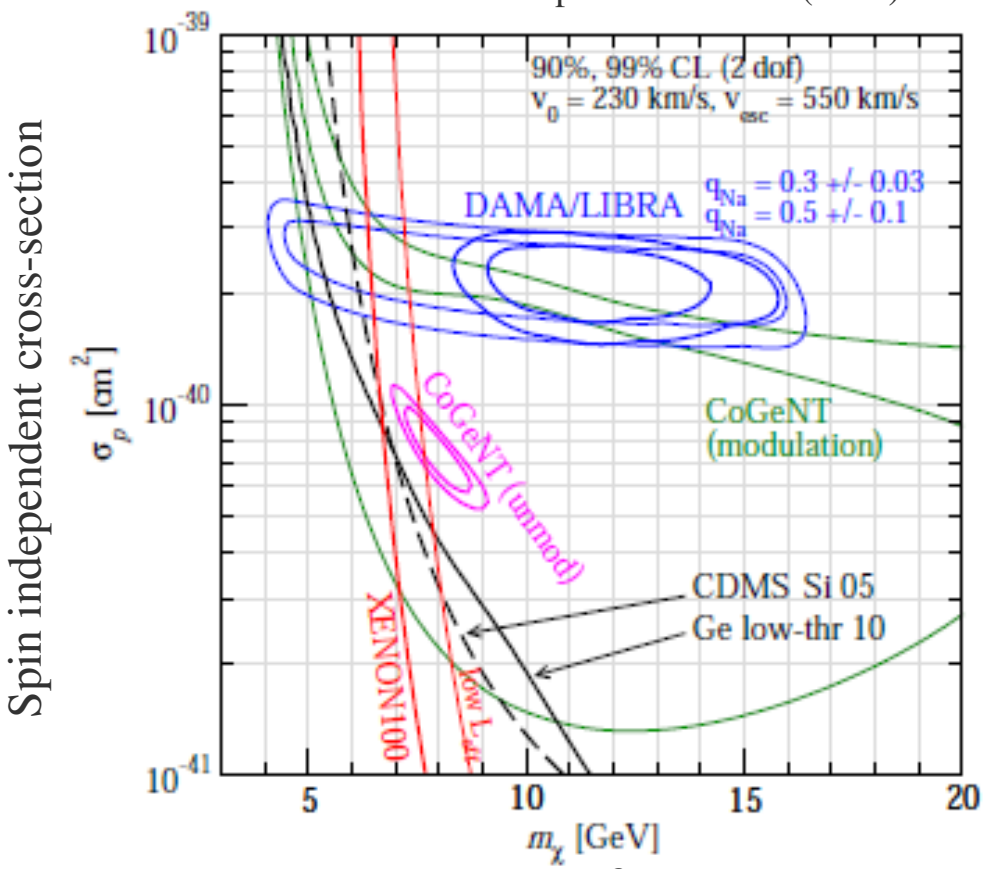
Preface: Motivation

Schwetz Zupan JCAP **1108** (2010) 008



Spin independent cross-section

Mass of DM

Some of the direct detection exps suggest

cf. also CRESST result

$$m_\chi \sim [7, 10]\ \text{GeV},$$

$$\sigma_{\chi N} \sim [10^{-41}, 10^{-40}]\ \text{cm}^2$$

and some of them disfavour this

Many discussion on the global fit

Arina Hamann Wong 1107.0717
Belli et al 1106.4667
Farina et al 1107.0715
Frandsen et al 1105.3734
Foot PL**B703** (2011) 7
Fox et al 1107.0717
Hooper Kelso 1106,1066

Which observation constrains what?

Our central concern: Can MSSM explain this light dark matter?

Recent studies: → Talk by Fornengo

Cao et al JHEP **1007** (2010) 044 Cumberbatch et al 1107.1604 Farina et al 1104.3572 Feldman Liu Nath PR**D81** (2010) 117701
Fornengo Scopel Bottino PR**D83** (2011) 015001 Kuflik Pierce Zurek PR**D81** (2010) 111701 Scopel et al PR**D83** (2011) 095016
Vasquez et al PR**D82** (2010) 115027 Vasquez Belanger Boehm 1108.1338

Outline

1. **Introduction**
   - Light DM in MSSM overview --- Higgs mediation→ Talk by Fornengo
   - Previous works
2. **Parameter space in MSSM** (with non-universal gaugino mass)
   - Constraints from two types of observables

     i) Depend only on Higgs sector, ii) Depend also on SUSY parameters
   - Future prospect
3. **Summary**

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2. **Parameter space in MSSM** (with non-universal gaugino mass)
   - Constraints from two types of observables

     i) Depend only on Higgs sector, ii) Depend also on SUSY parameters
   - Future prospect --- **Future is Now!**

     LHC Higgs search, LHCb and Xenon100
3. **Summary**

1 **Introduction**

1 Light DM in MSSM

- **How can we have such a light neutral particle in MSSM?**

  → Light "lightest neutralino" DM

  According to PDG,

  Mass $m_{\tilde{\chi}_1^0} > 46$ GeV, CL = 95%

  Assumptions include:

  5) Gaugino mass unification at the GUT scale.

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$$M_{\tilde{\chi}_1^0} \sim M_1 \ll M_2, \mu$$

Chargino mass

→ Bino-like DM

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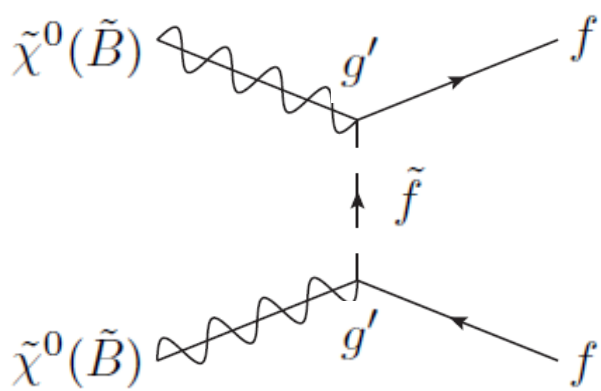
  → Bino-like DM

- **Can such a light neutralino satisfy nature of DM?**

  $\Omega_\chi h^2 \sim 0.1$ → Efficient annihilation process is necessary

  Sfermion med.



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Dreiner et al EUJ **C62** (2009) 547

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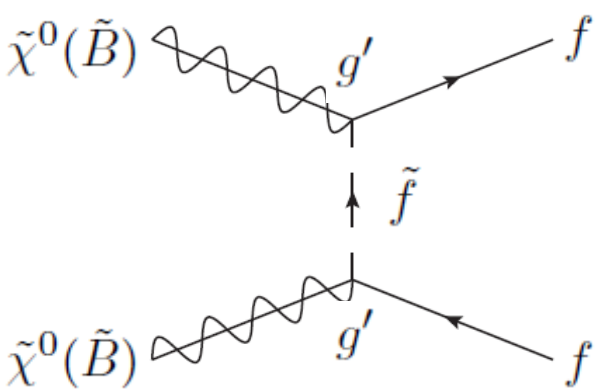

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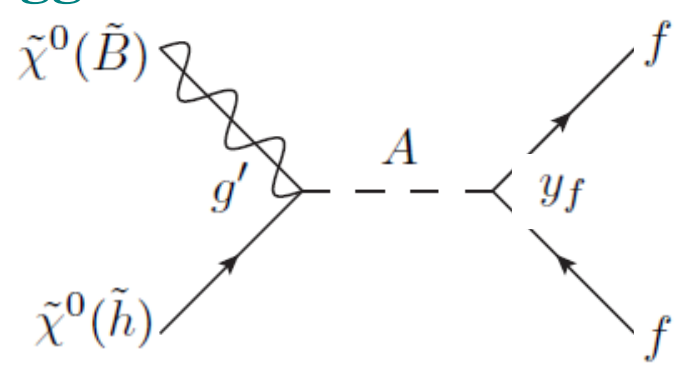
Higgs med.

Drees Nojiri PR**D47** (1993) 376
Bottino Fornengo Scopel PR**D67** (2003) 063519



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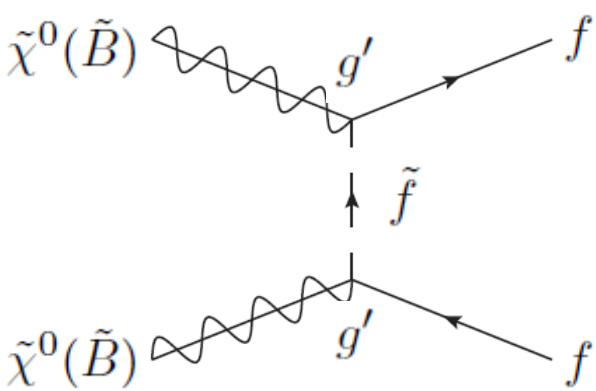

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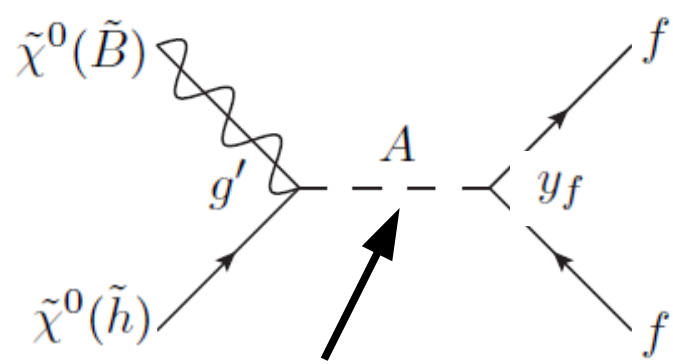

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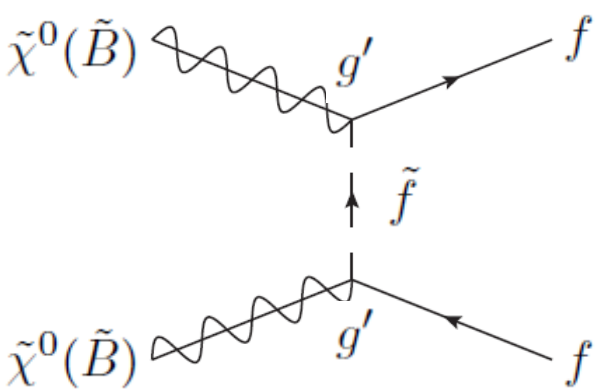

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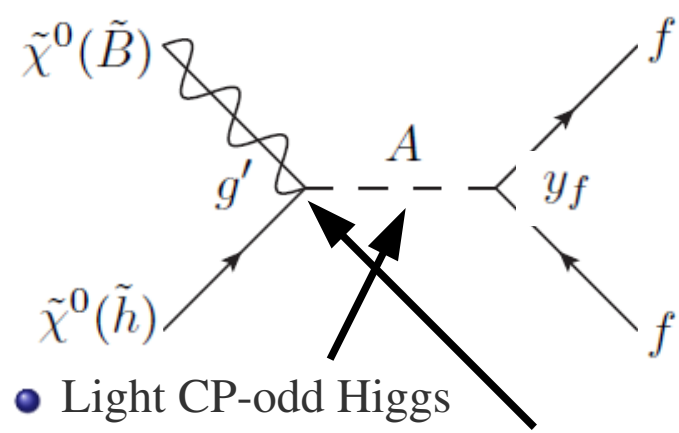

- Light CP-odd Higgs
- Signifiacant higgsino component → Small μ-term

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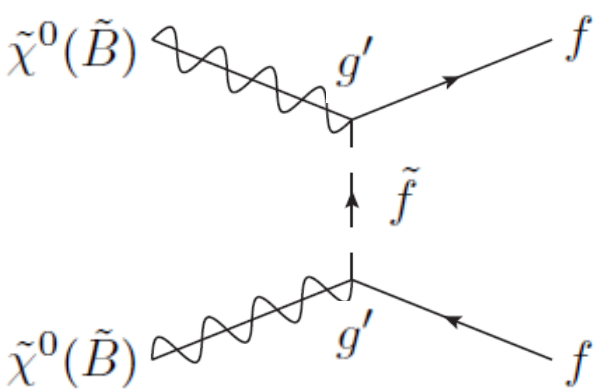

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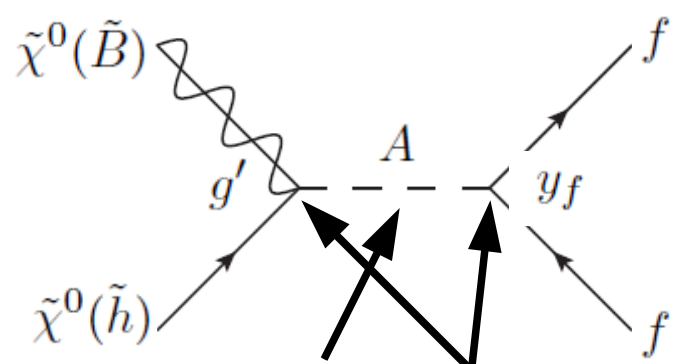

- Light CP-odd Higgs
- Signifiacant higgsino component → Small μ-term
- $\tan\beta$ enhancement (for bottom)

1 Light DM in MSSM

- The light Bino-like DM scenario requires the following param. choice:

$M_1 \sim 10$ GeV

$m_A \sim 100$ GeV

$\mu \sim$ small

$\tan\beta \sim$ large

- light $M_{\tilde{\chi}_1^0}$
- Correct relic density (Higgs mediation)

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- light $M_{\tilde{\chi}_1^0}$
- Correct relic density (Higgs mediation)

- This parameter choice is challenging, because...
  - Large $\tan\beta$ and light m_A

    enhance the extra-contributions to flavour physics processes

    See e.g., Buras et al (2002) Isidori and Paradisi (2006) Barenboim et al (2007) Eriksson et al (2008) Altmannshofer et al (2009) Altmannshofer and Straub (2010)

  - Light neutralino with a large higgsino comp. contributes to invisible decay width of Z

- We will check the low energy constraints to this scenario...

2 **Parameter space in MSSM**

2 Two types of constraints

- We employ the following observables to constrain MSSM parameters

$$\tan\beta, \quad M_1, \quad M_2, \quad M_3, \quad a_0, \quad \mu, \quad m_A, \quad m_{\tilde{q}}, \quad m_{\tilde{\ell}},$$

Group 1.

$B^+ \to \tau^+\nu \quad B^+ \to D^0\tau^+\nu$

$K^+ \to \mu^+\nu \quad D_s^+ \to \tau^+\nu$

→ Essentially determined by $m_{H^\pm}$ and $\tan\beta$

Group 2.

$b \to s\gamma \quad B_s \to \mu^+\mu^-$

→ Involved SUSY param dependence A_t, $m_{\tilde{t}}$, $\tan\beta$, etc.

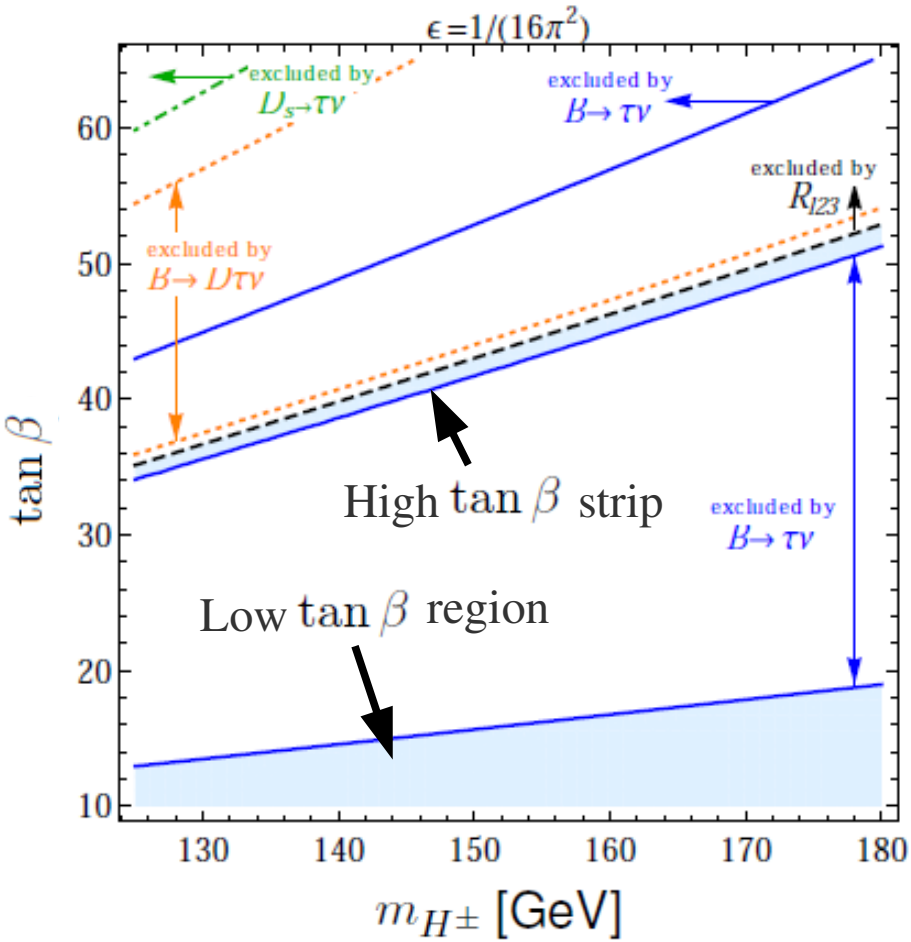
- We also take into consideration
  - Invisible decay width of Z
  - Search for neutralino pair production at LEP
  - Mixing-dependent bound to the lightest Higgs mass

- We apply the constraint of each observable (95%CL) "one-by-one".

  We do not construct the unified χ^2 to see which observable constraints what.

2 Estimation with analytic formula

Constraints from **Group.1** obs.



$$0.52 < R_{B\tau\nu} < 2.61 \qquad 0.985 < R_{\ell 23}(K \to \mu\nu) < 1.013$$

$$0.151 < R_{D\ell\nu} < 0.681 \qquad 4.7 \times 10^{-2} < \mathrm{BR}(D_s \to \tau\nu) < 6.1 \times 10^{-2}$$

See e.g.,FlaviaNet arXiv:0801.1817
Antonelli et al ERJ **C69** (2010) 399

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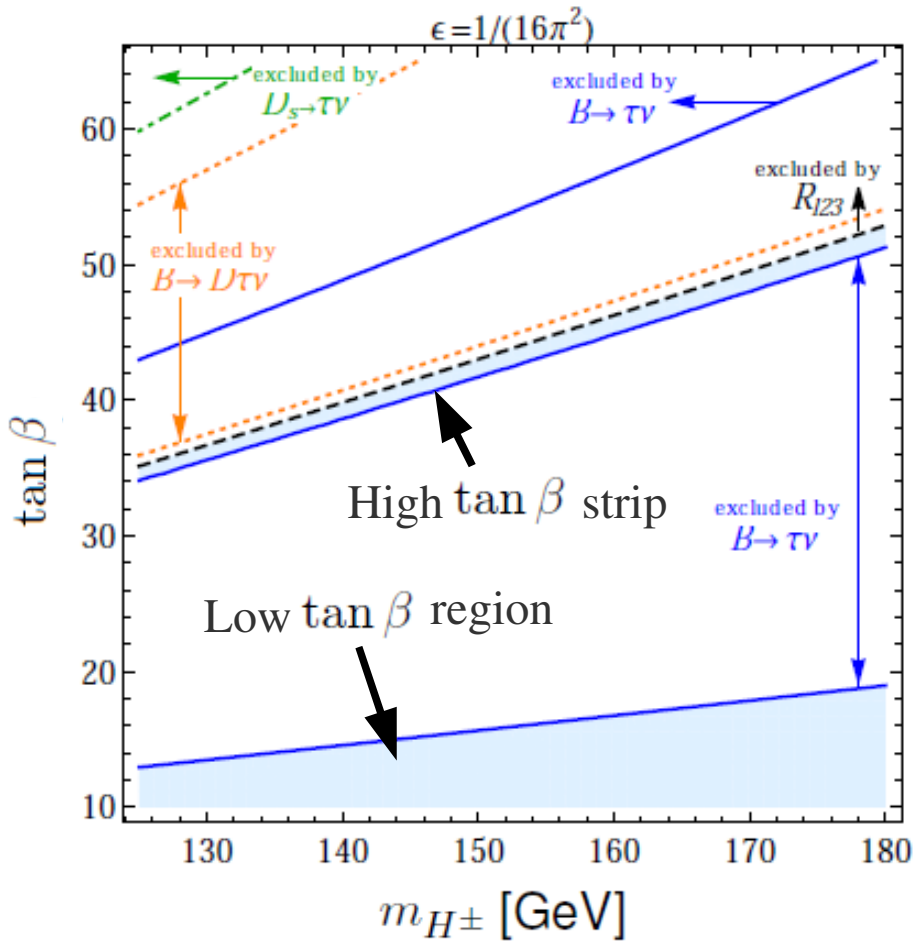
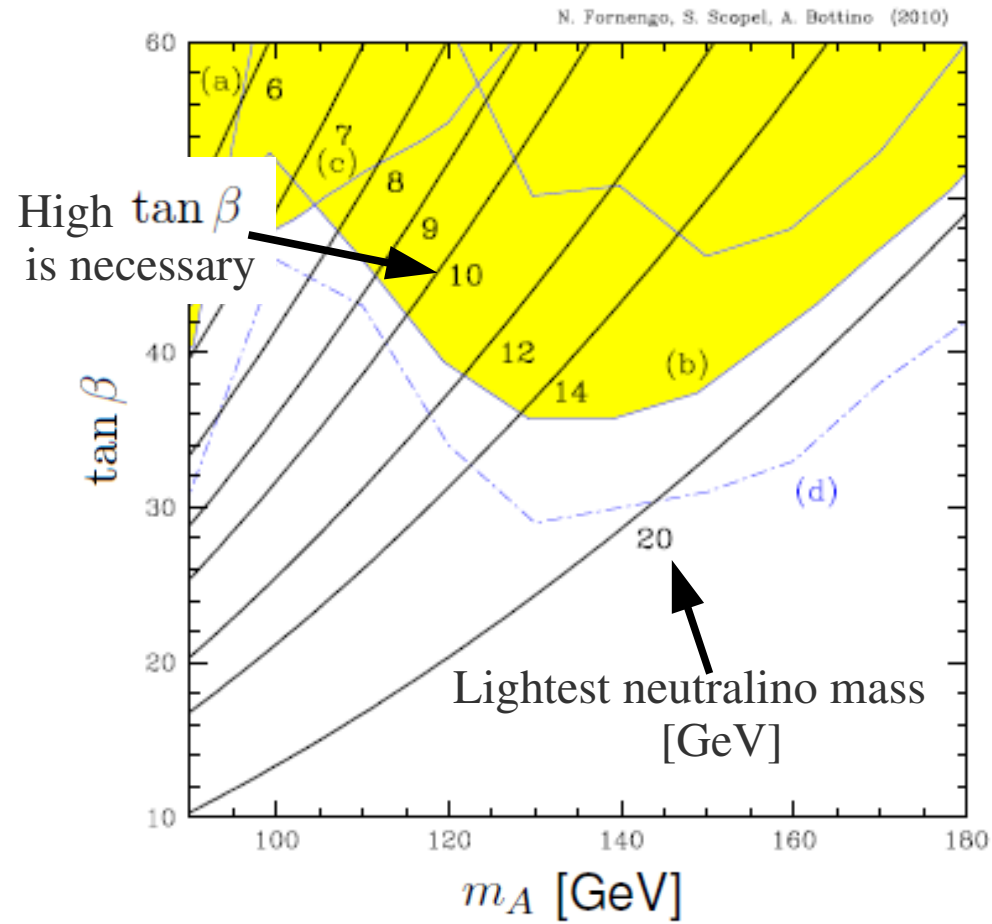


Constraint from relic density

Fornengo Scopel Bottino PR**D83** (2011) 015001



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Observables are complementary to constrain the parameter space

2 Numerical analysis

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- Parameters and their scanning range

$$\tan\beta, \quad M_1, \quad M_2, \quad M_3, \quad a_0, \quad \mu, \quad m_A, \quad m_{\tilde{q}}, \quad m_{\tilde{\ell}},$$

$$M_1 \in [7, 30]\ \text{GeV}, \qquad M_2 \in [100, 600]\ \text{GeV}, \qquad M_3 \in [400, 1200]\ \text{GeV},$$

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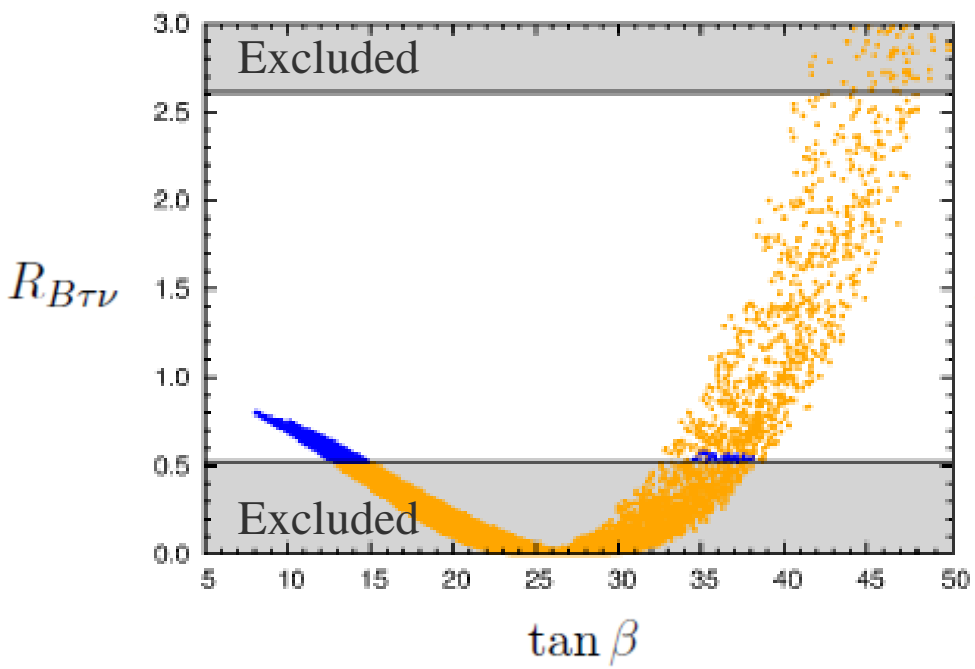

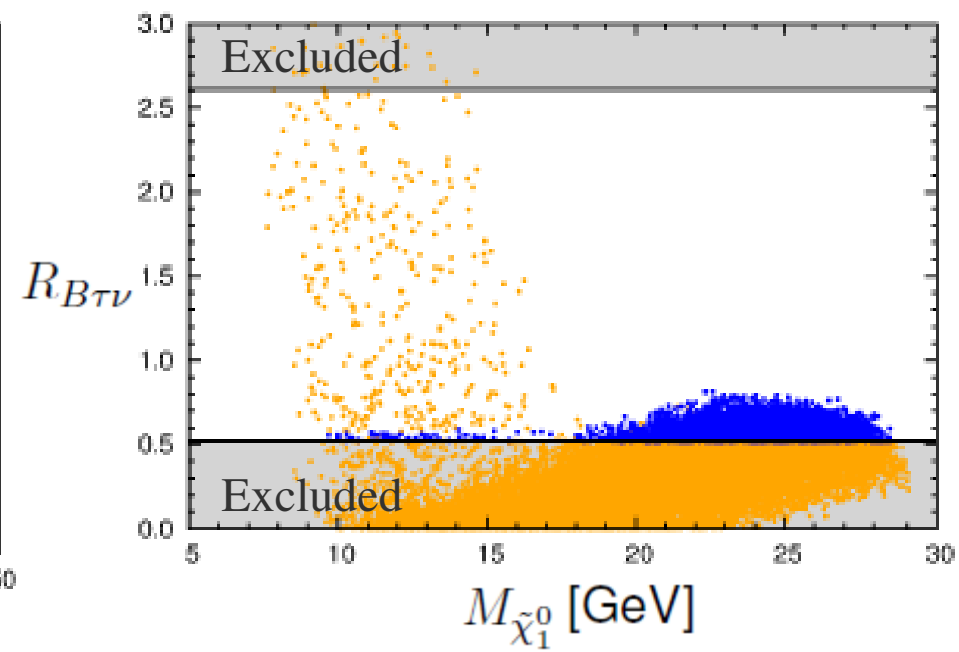

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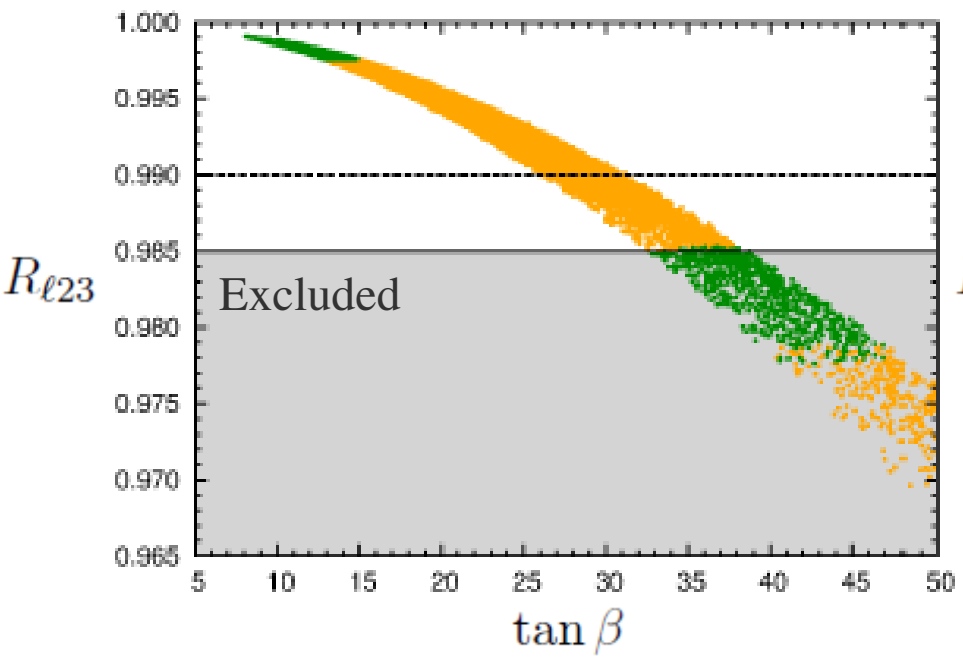

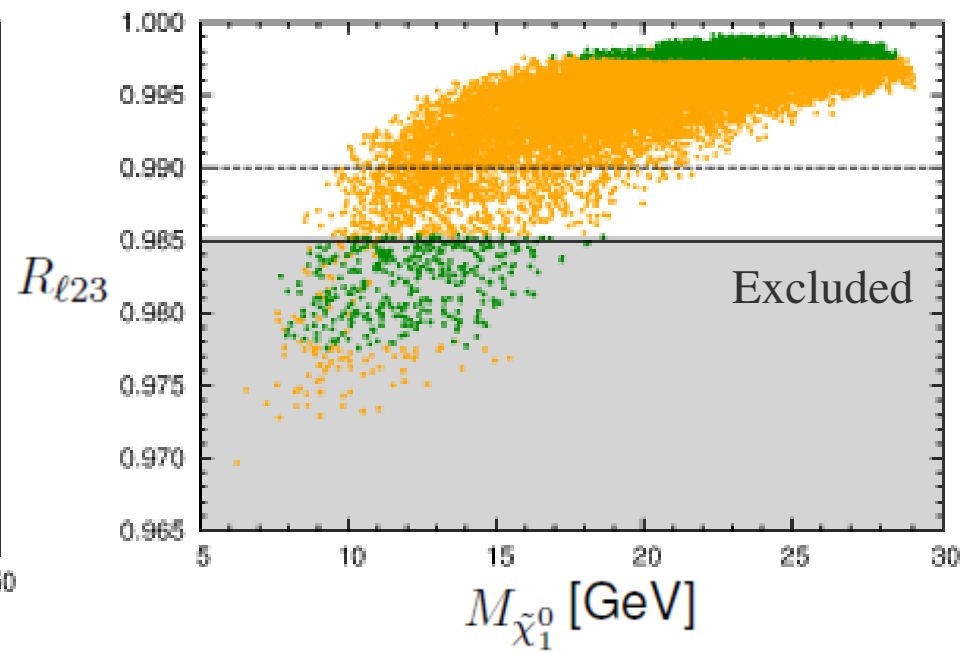

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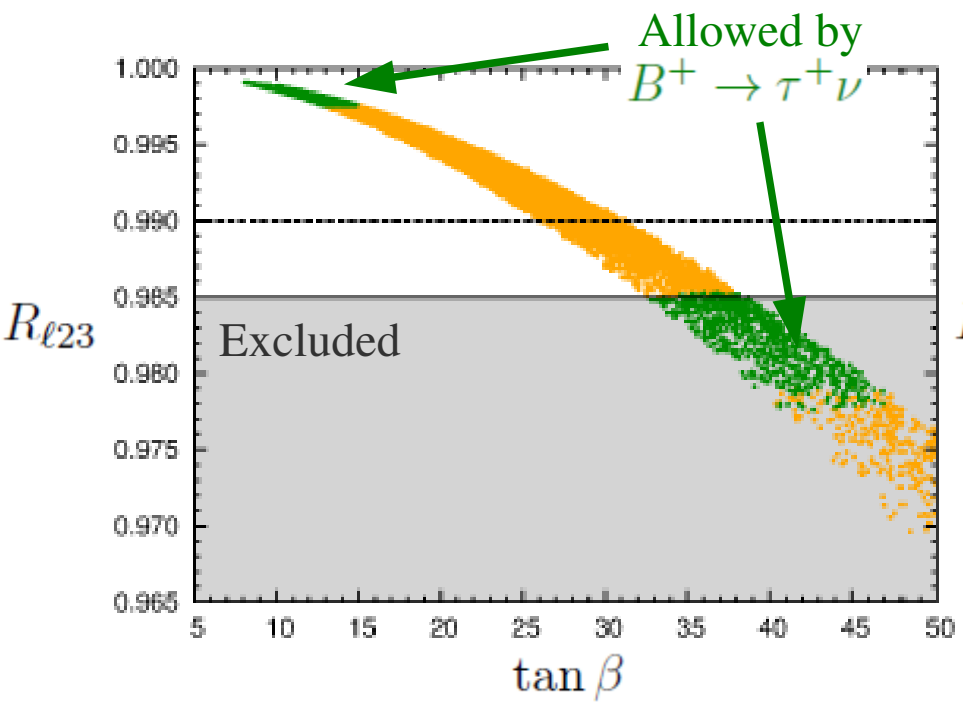

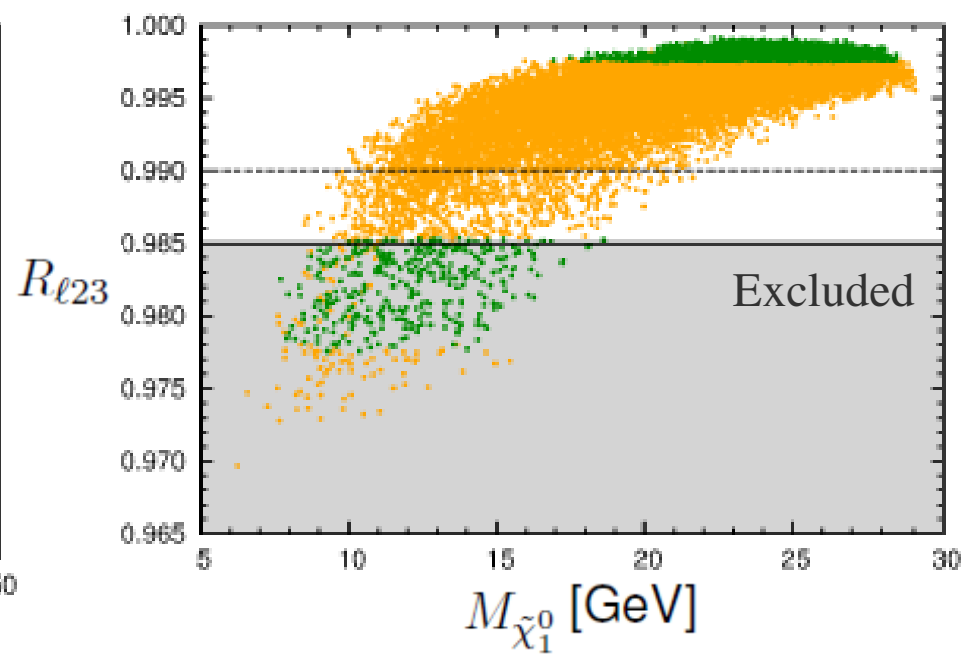

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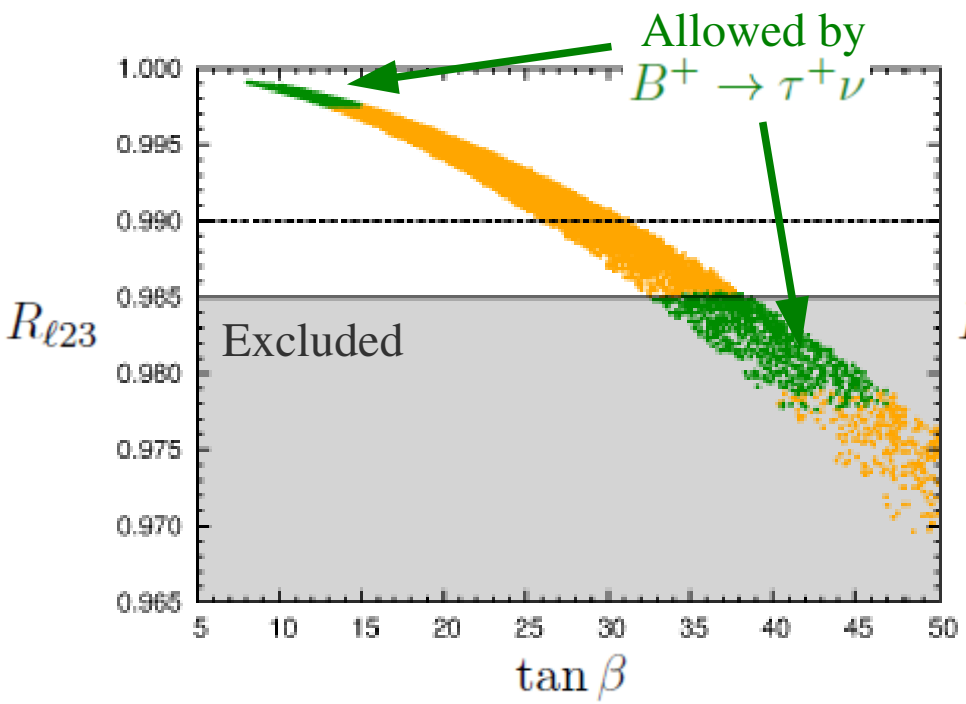

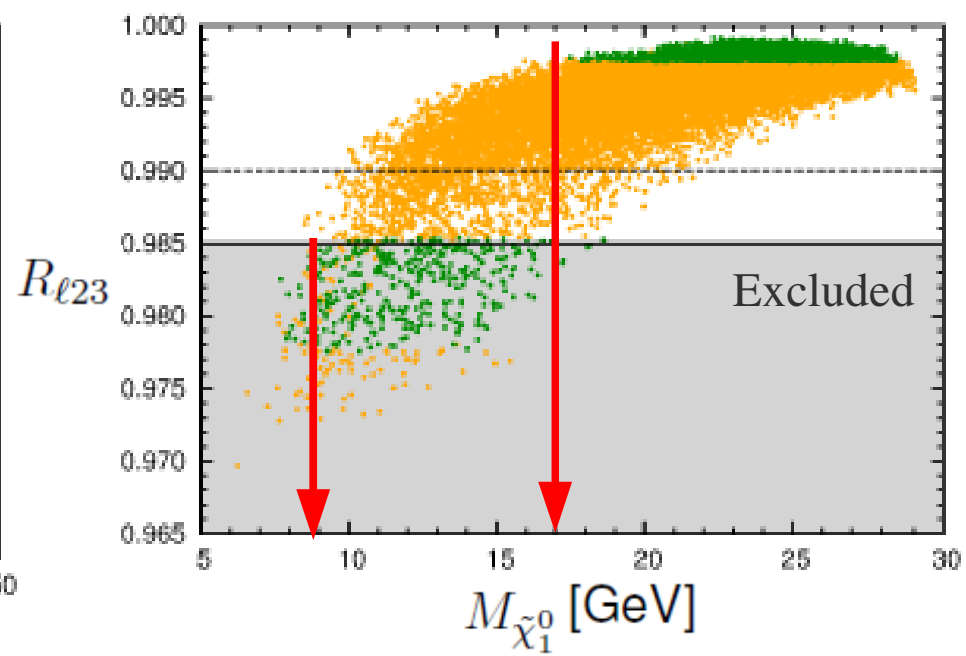

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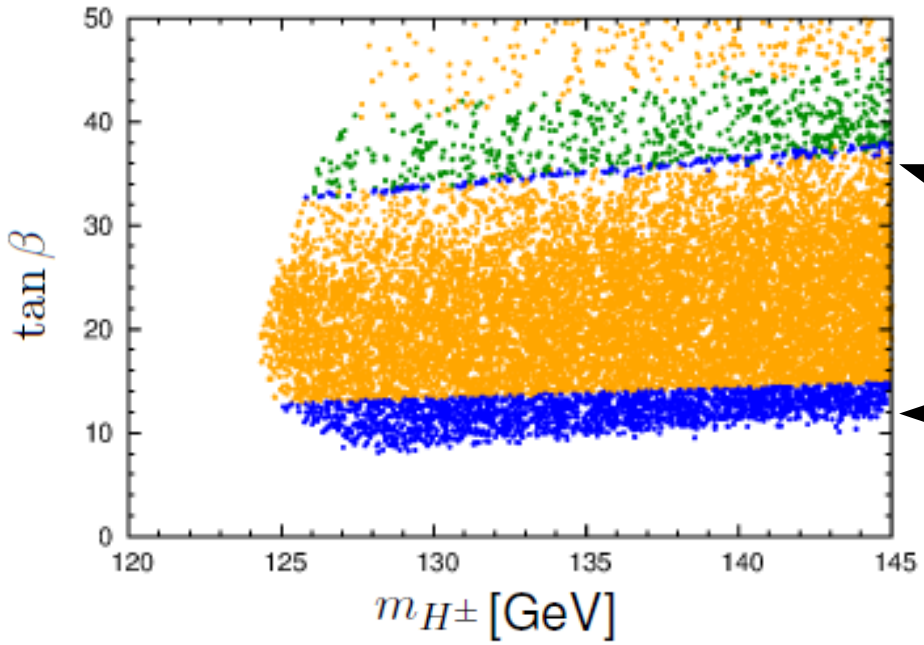
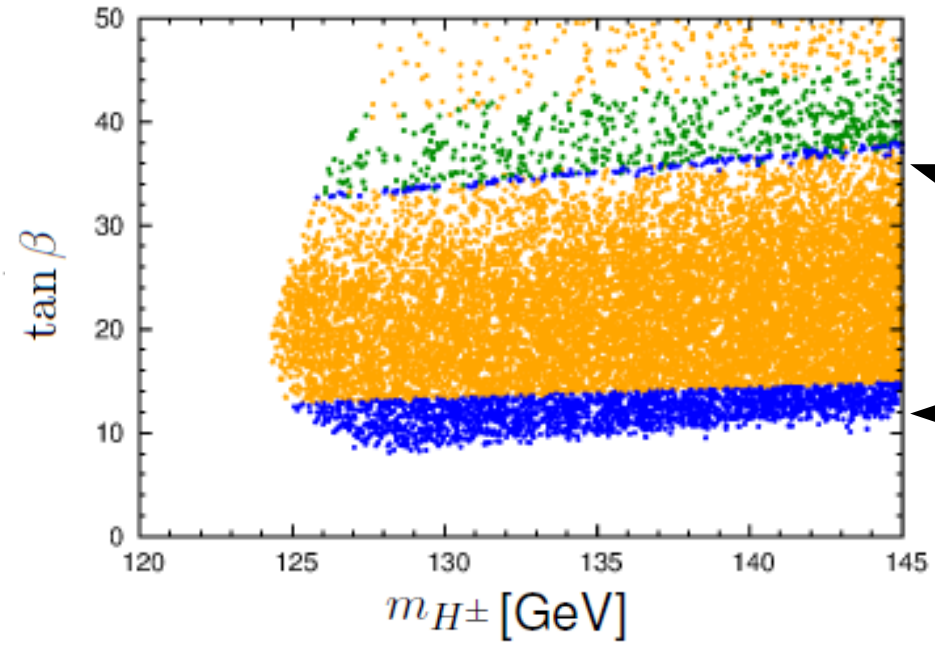
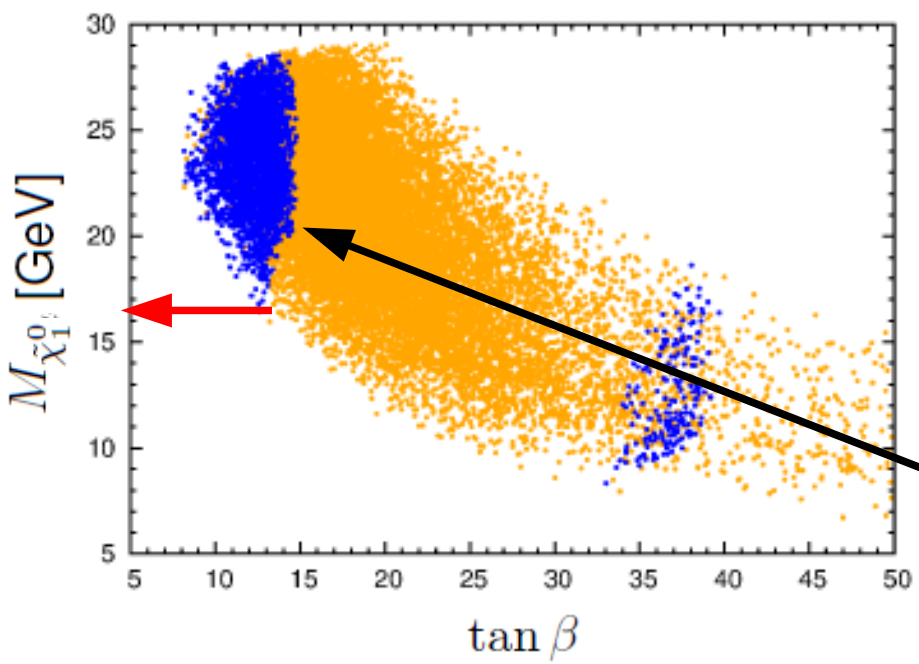


- After applying the all constraints, two separated regions are left.
  - High $\tan\beta$ strip
  - Low $\tan\beta$ region

2 Numerical analysis

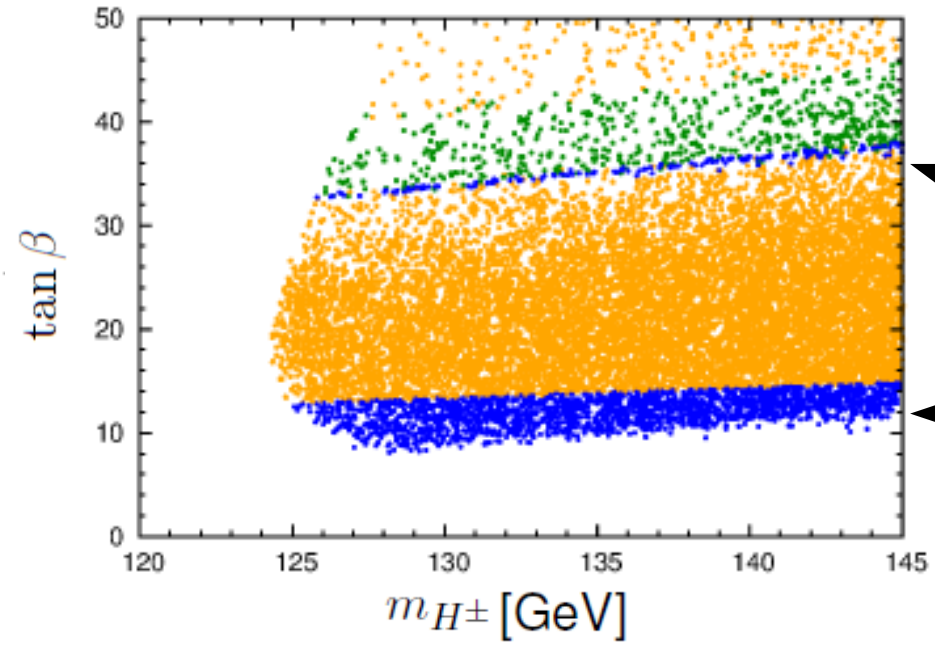


- After applying the all constraints, two separated regions are left.
  - High $\tan\beta$ strip
  - Low $\tan\beta$ region



- On the low $\tan\beta$ region
  $M_{\tilde{\chi}_1^0} \gtrsim 16$ GeV

2 Numerical analysis



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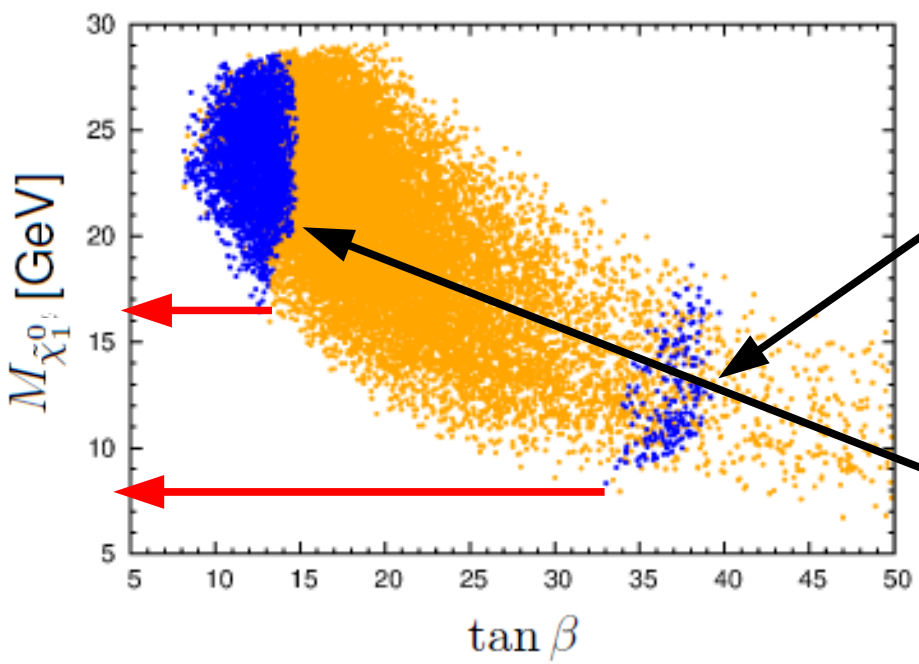
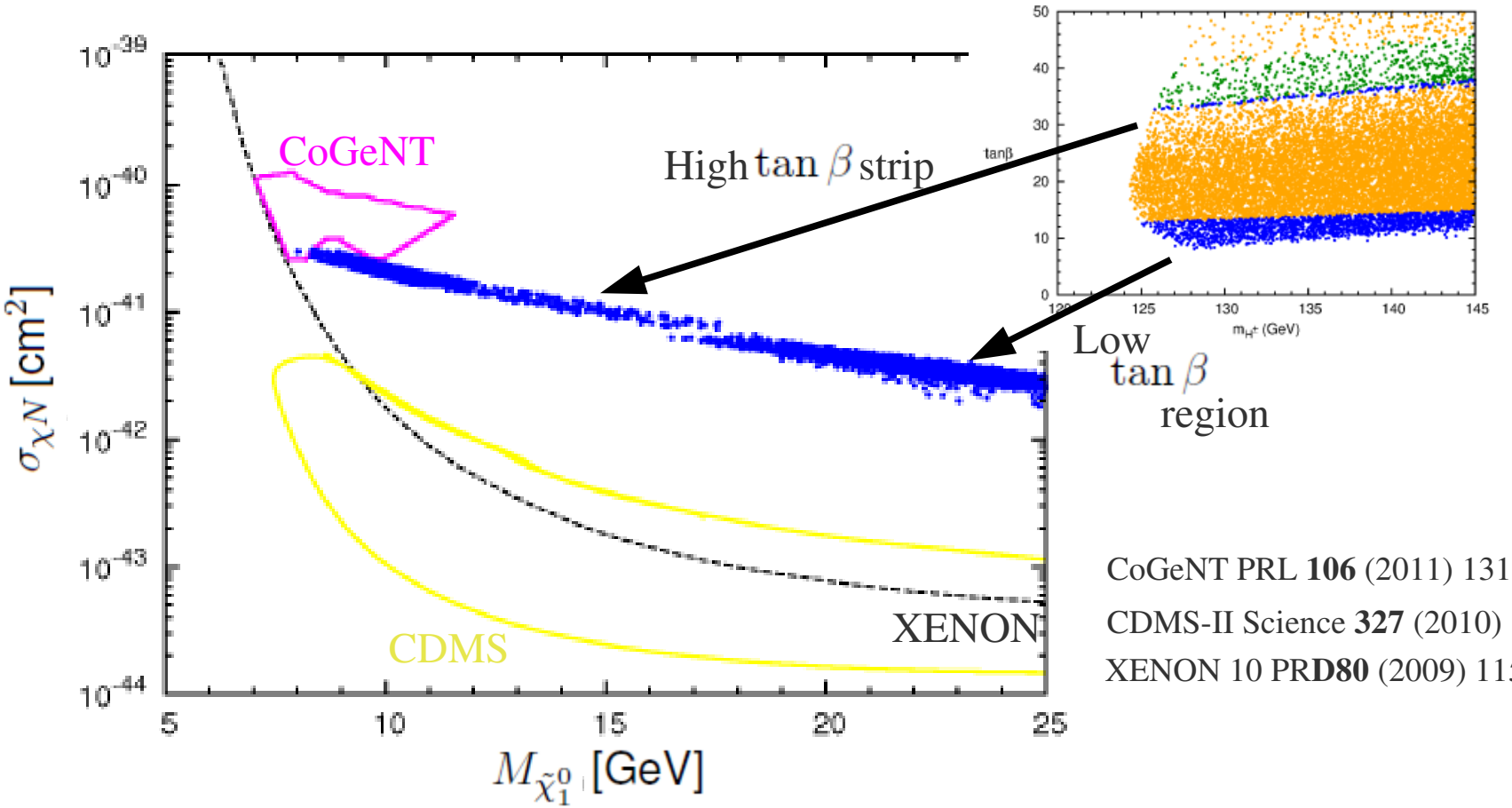


- On the high $\tan\beta$ strip
  $M_{\tilde{\chi}_1^0} \lesssim 10$ GeV
  favourable by DAMA and CoGeNT
  → Let us check the SI cross-section...
- On the low $\tan\beta$ region
  $M_{\tilde{\chi}_1^0} \gtrsim 16$ GeV

2 Numerical analysis



CoGeNT PRL **106** (2011) 131301
CDMS-II Science **327** (2010) 1619
XENON 10 PR**D80** (2009) 115005

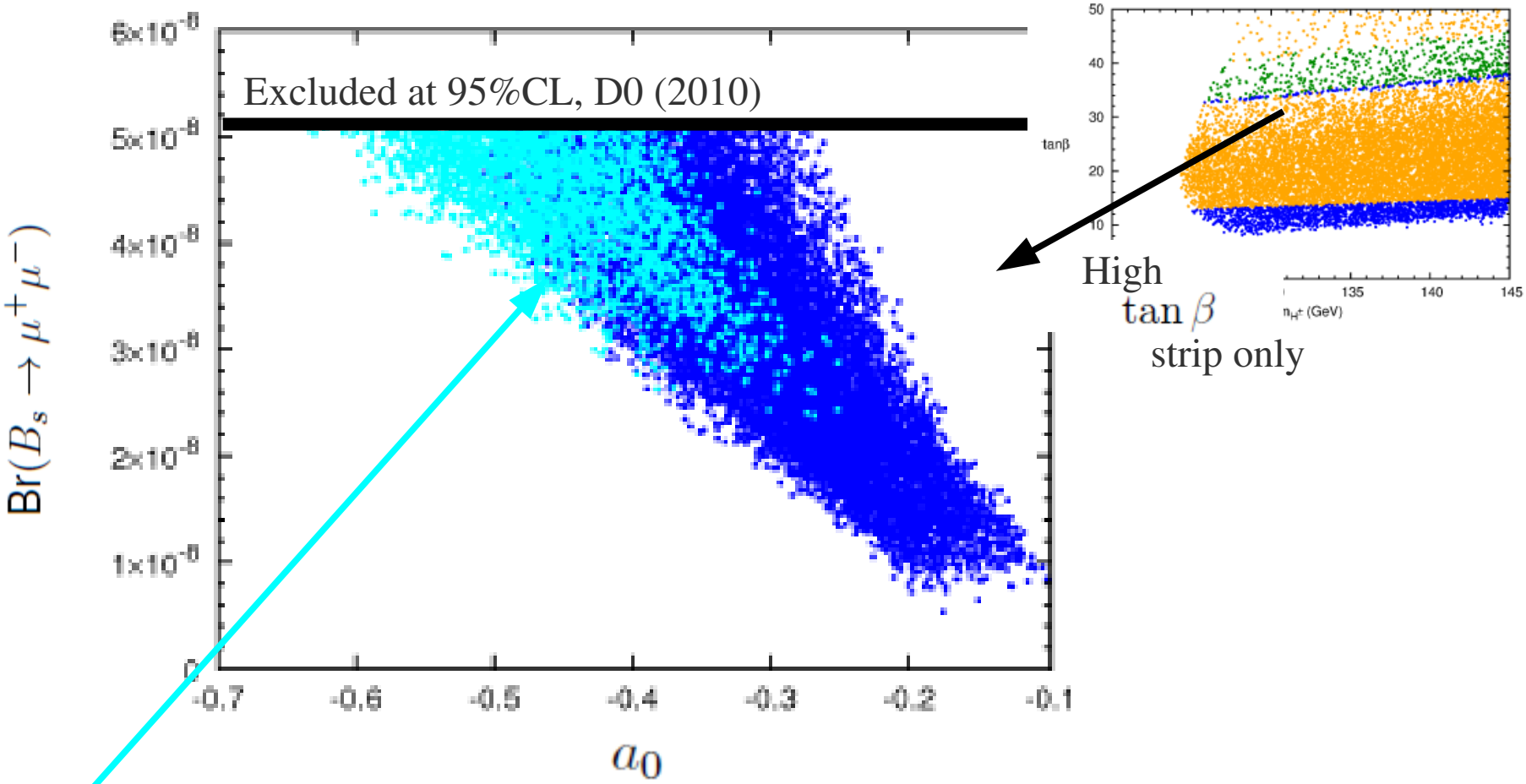
High $\tan\beta$ strip is more-or-less consistent with CoGeNT result

→ Fine-tuned region so that $B^+ \to \tau^+\nu$ and $K^+ \to \mu^+\nu$ are satisfied

→ Future improvement of the bounds will exclude high $\tan\beta$ strip

2 Future is Now!

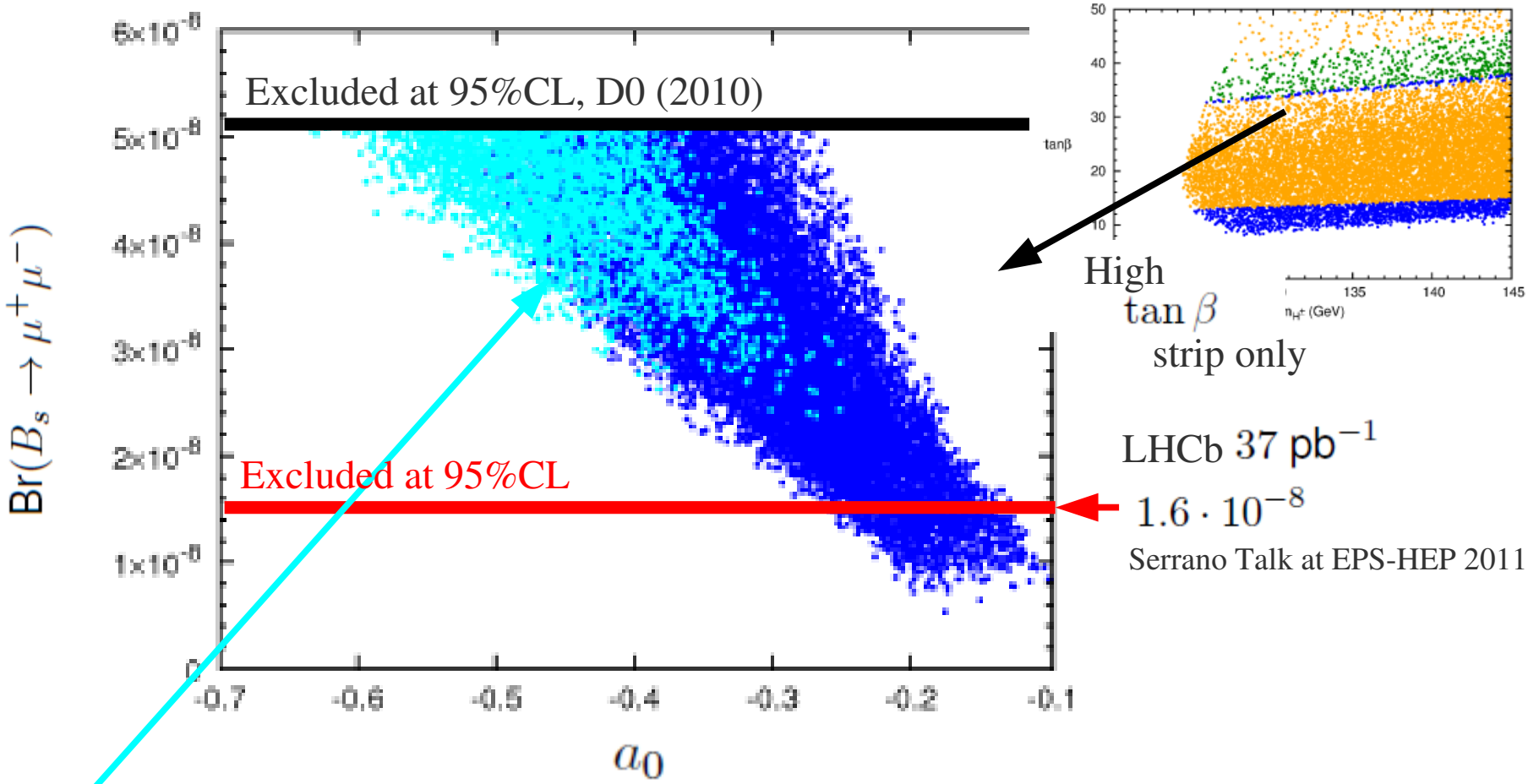
- Successful run of LHC already starts constraining the parameter space...



Lightest Higgs mass clears the LEP bound (mixing angle dependent)

2 Future is Now!

- Successful run of LHC already starts constraining the parameter space...

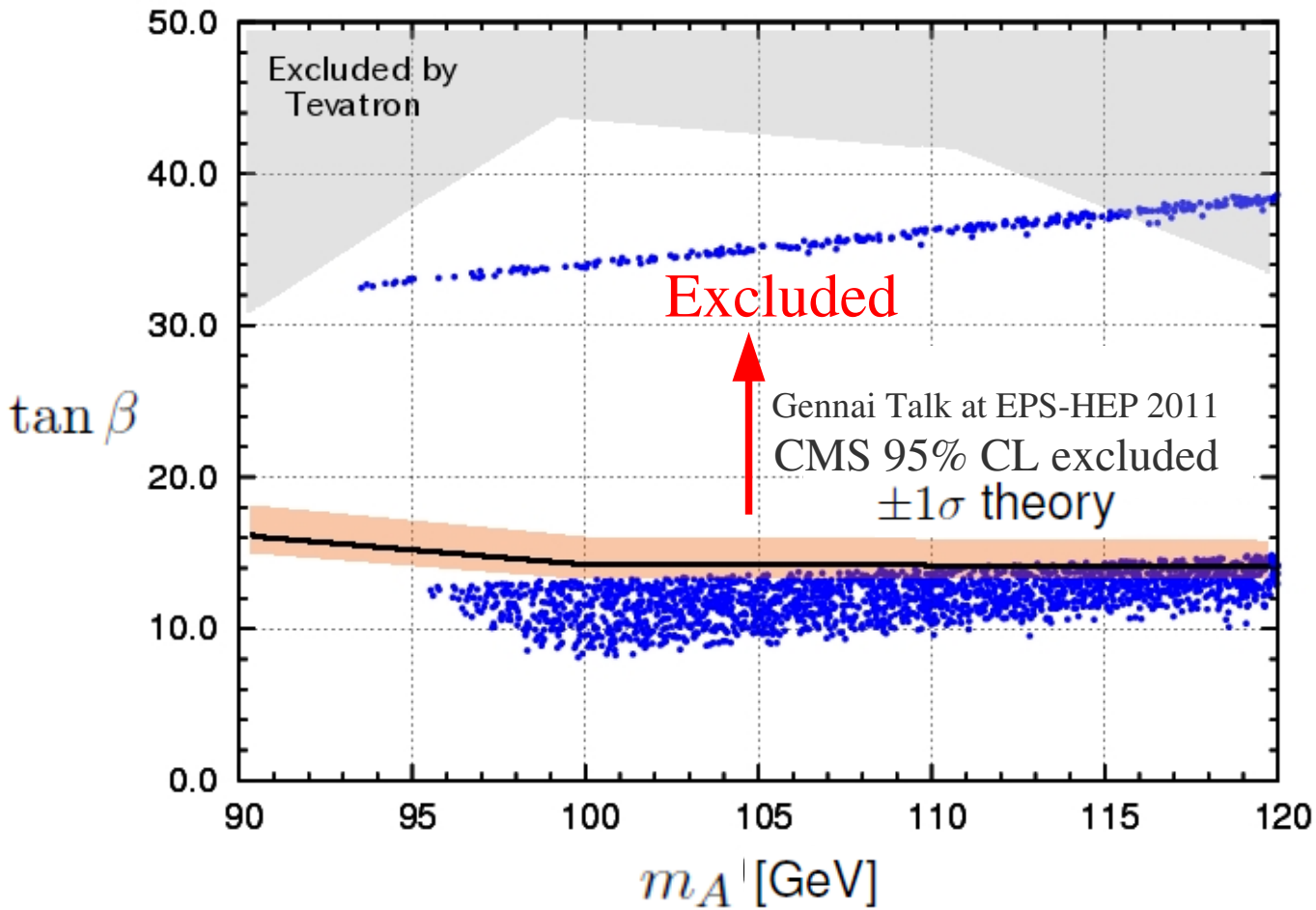


Lightest Higgs mass clears the LEP bound (mixing angle dependent)

Combination of $B_s \to \mu^+\mu^-$ and m_h excludes the high $\tan\beta$ strip

2 Future is Now!

- Successful run of LHC already starts constraining the parameter space...



High $\tan\beta$ region is also excluded by Higgs search at CMS

For discussion on uncertainty in Higgs search at LHC → Baglio and Djouadi arXiv:1103.6247

3 Summary

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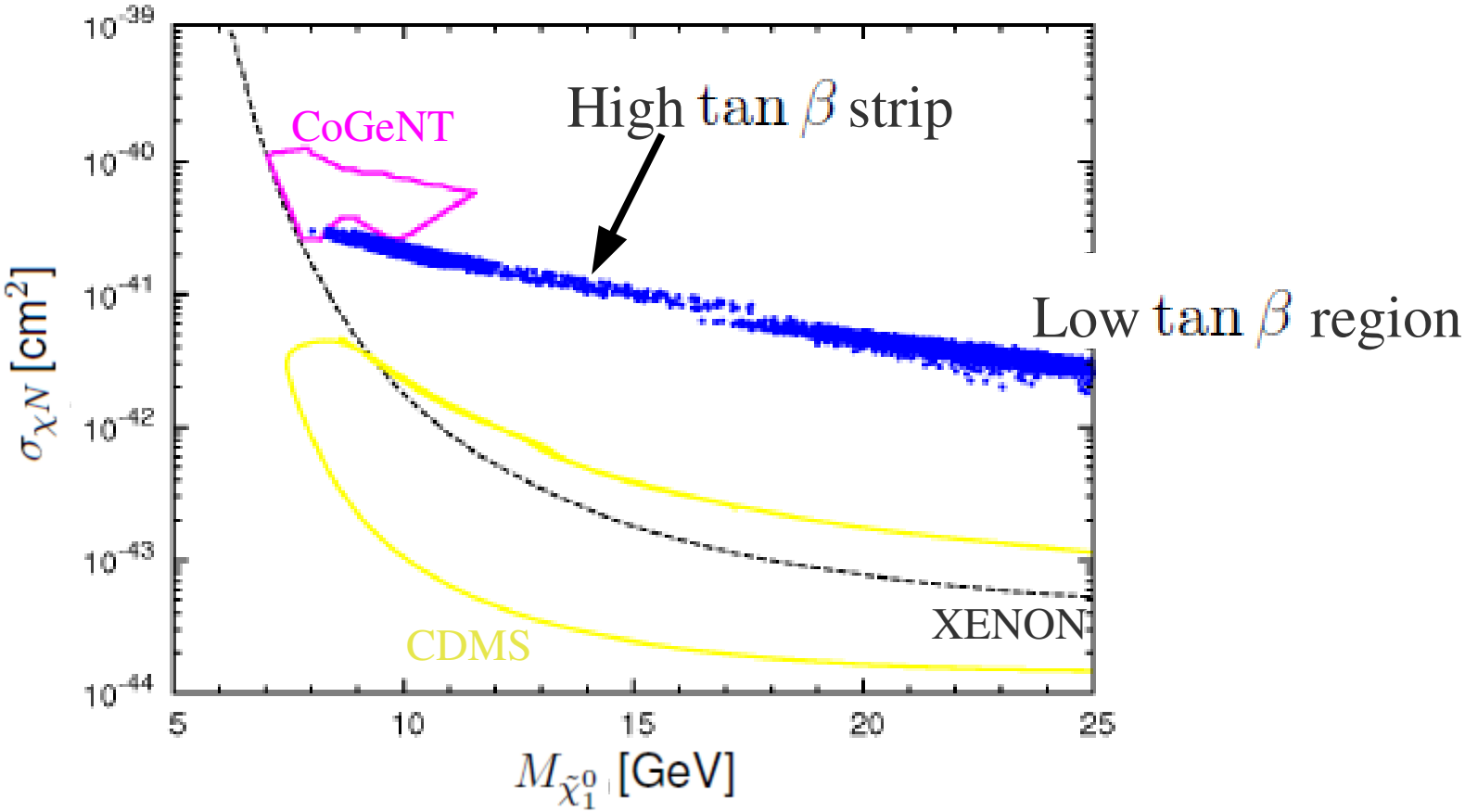
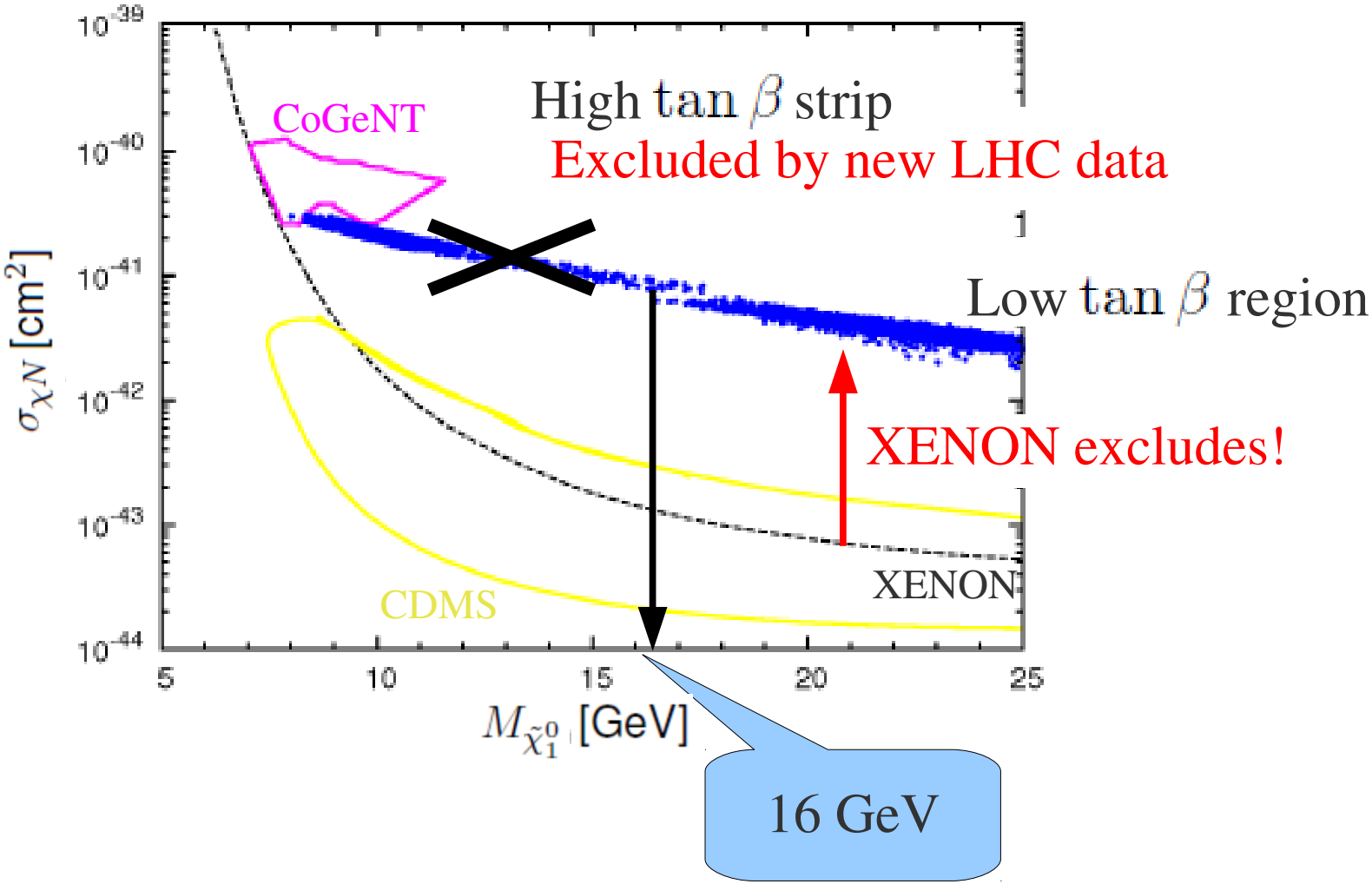

CoGeNT
High tan β strip
Low tan β region
XENON
CDMS
$\sigma_{\chi N}$ [cm^2]
$M_{\tilde{\chi}_1^0}$ [GeV]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
5
10
15
20
25

3 Summary



- After taking into account new LHC data → $M_{\tilde{\chi}_1^0} \gtrsim 16$ GeV (Higgs med.)
- After taking into account XENON100 data → Higgs med. is excluded
  → Slepton mediation → $M_{\tilde{\chi}_1^0} \gtrsim 13$ GeV Vasquez Belanger Boehm 1108.1338